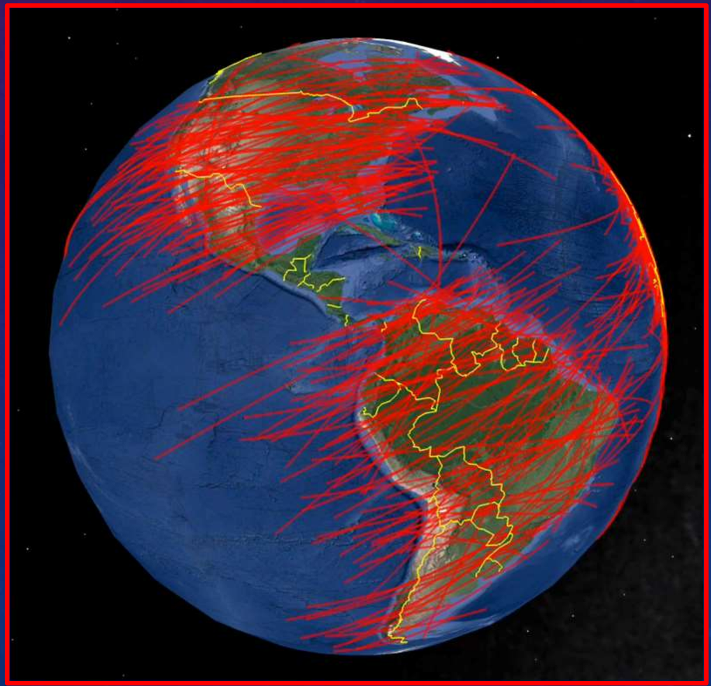
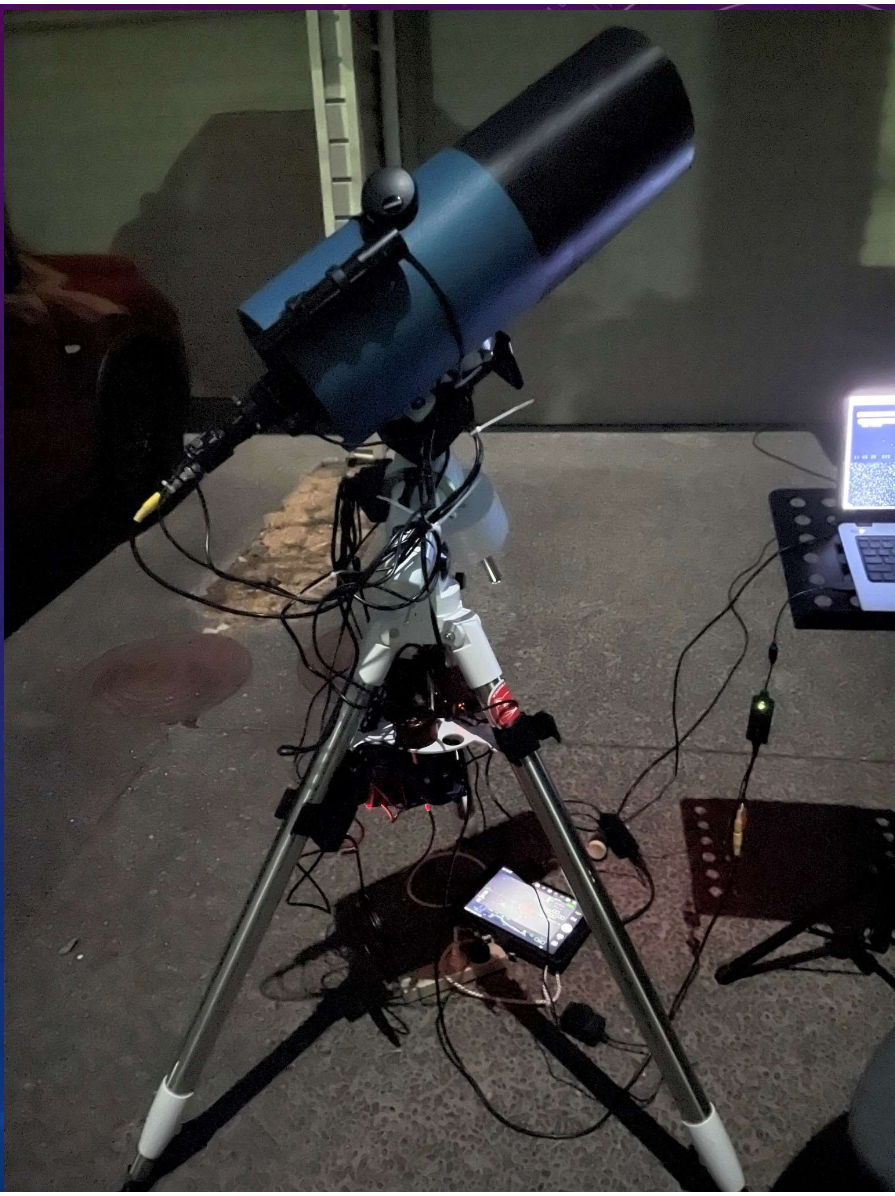
GPS FLASH TIMING



Michael Camilleri. April 2024. mcamilleri69@gmail.com

WHY GPS FLASH TIMING?

- Accurate timing using 1 PPS GPS flashes synced to GPS satellite time and UTC
- Usable with any type of camera, analog or digital
- Simpler setup than analog VTI
- Cheaper and more accessible especially for new or casual observers or large campaigns
- Future proof - not dependent on ongoing production of IOTA-VTI, legacy analog video or single developers



GPS FLASH TIMING METHODS

Two main methods:

- “Smart” GPS flasher with logged GPS timestamps:
  - Aart’s flashers, Chronoflash, new IOTA-GFT etc

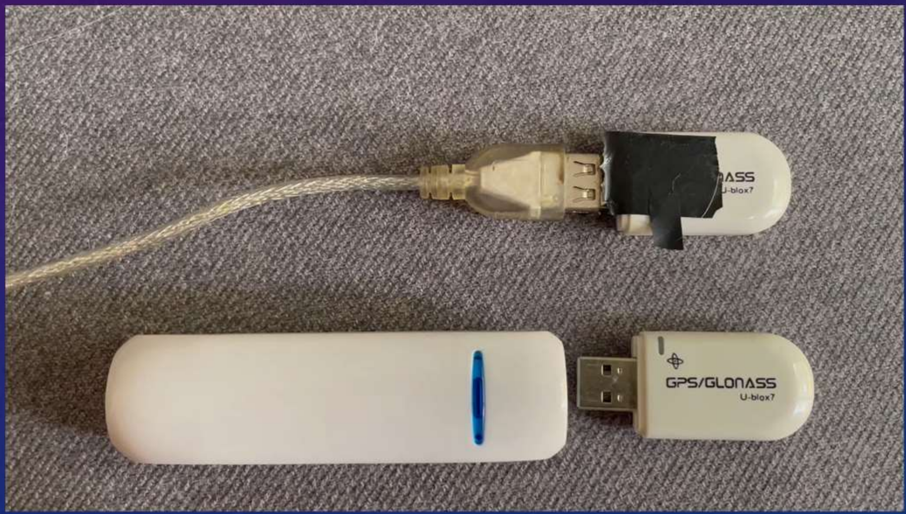
- “Dumb” GPS flasher using corrected recording system timestamps
  - JOIN/IOTA-EA system
  - Method of Le Cam

- Will demonstrate method of Le Cam using a “Dumb” GPS flasher
- Discuss issues that affect all GPS flash timing systems

GPS FLASH SOURCES

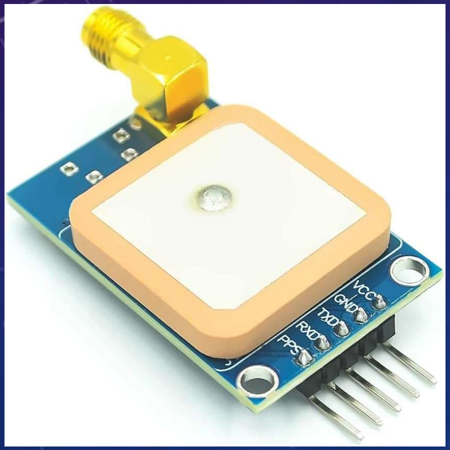
HiLetGo VK172 USB GPS Receiver

- $US12 from Amazon
- Same as used by JOIN/IOTA-EA
- Simple GPS device with a 1 PPS flashing LED
- Powered via USB cable or small USB powerbank
- Trivial modification to destroy the Red ‘On’ status LED with a craft knife
- No DIY build, soldering, programming, 3D printing etc



FANCIER GPS FLASH SOURCES

- Can also build a simple flasher using any U-BLOX series 6, 7 or 8 receiver with basic soldering to connect LED and perhaps an intensity control
- GlobalSat BU-353N5 or similar might be useable for both flash and PC time – untested
- Separate antenna for faster satellite acquisition and better stability



THE PC/RECORDING SYSTEM TIME

- “Dumb” GPS flash pulses are not logged so need to know the nearest UTC second
- Use the PC system time, disciplined by NTP (Meinberg NTP) or by a GPS time receiver sync via BktTimeSync or NMEATIME2
- Remote time sync possible using 4G/5G hotspot or GPS USB receiver
- PC time **MUST** be accurate to <<1 s so the nearest UTC second can be reliably identified
- ~100 ms accuracy is OK
- Must record with timestamped frames
  - Recommend using SharpCap – ADV format (upcoming SharpCap release) or SER format for video, or FITS
  - Can use AVI format with on-screen timestamps but not recommended

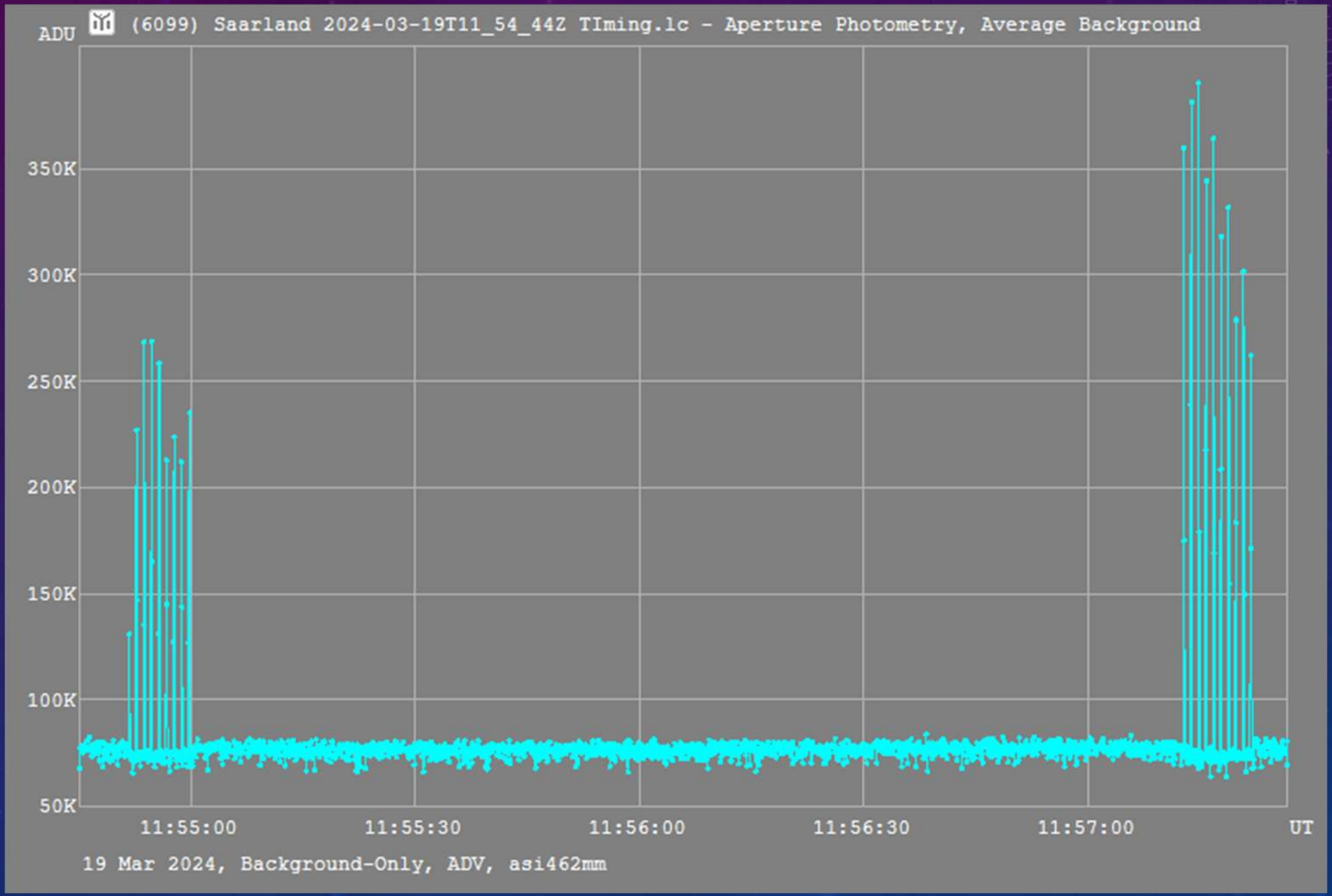
FLASH TAGGING THE OBSERVATION

- I usually do a 3 minute recording with GPS flashes near start and end
- Put a series of GPS flashes down the scope tube before and after the expected time
- Position the GPS flasher to get even illumination with no saturation – aim for 30-50% on the histogram
- Can alter the position or angle to control illumination or cover with tape – experiment
- Exposure times NOT multiples or divisors of 100 ms to ensure first frame has a decent amount of flash time in it. Use 40, 80, 160 ms, 190 ms, 240 ms etc.
- Series of flashes ensure there should be some usable flashes given handheld illumination and the time cycling

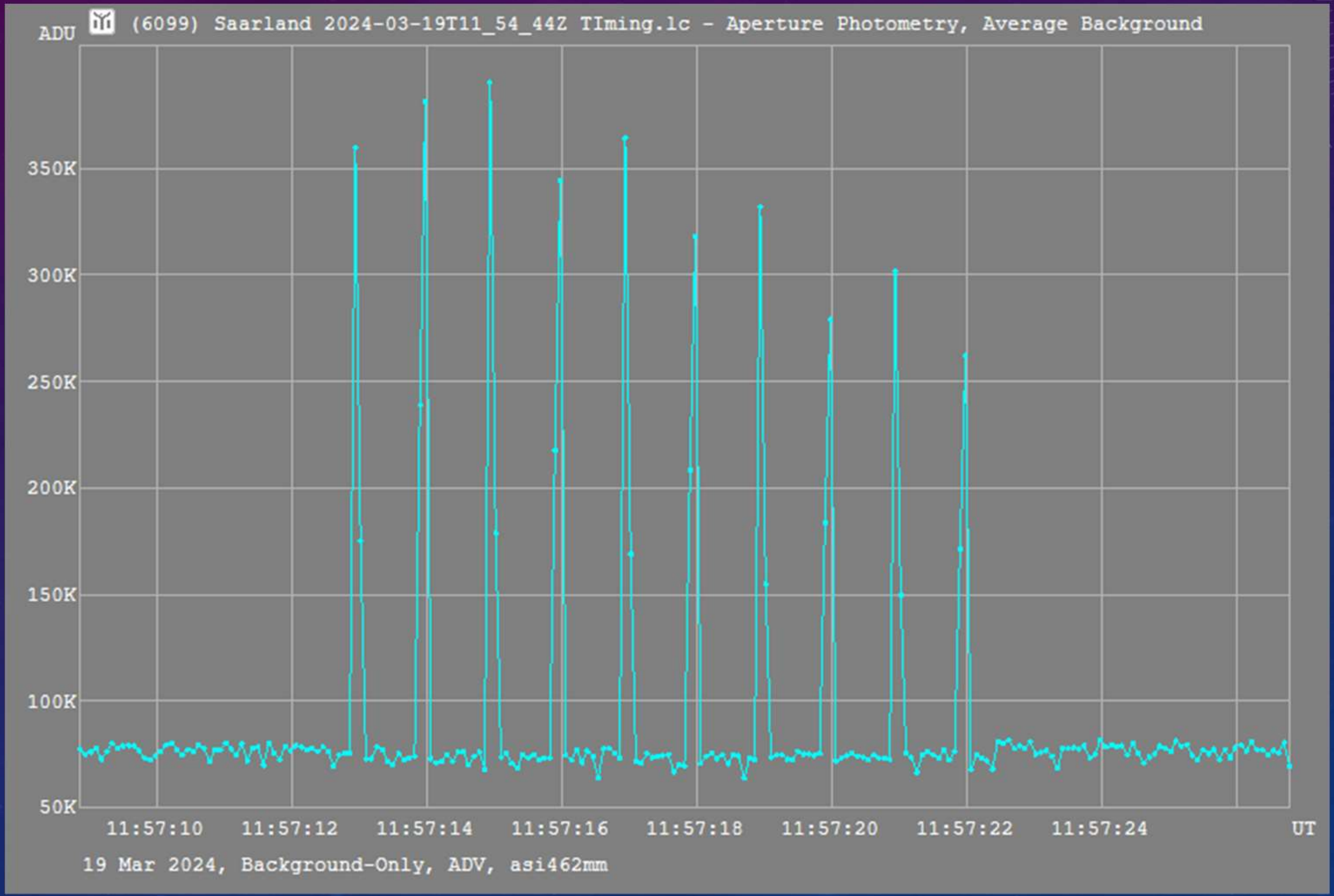
LIGHT CURVE MEASUREMENT USING TANGRA

- Use TANGRA or other light curve reduction to measure the offset
- Set a suitable measurement aperture depending on your camera and mount (details later)
- Use Aperture photometry for aperture background, not PSF or anything fancy
- Set the Acquisition delay to 0 and disable NTP offset when it pops up
- Generate the light curve and save CSV

LIGHT CURVE WITH GPS FLASHES – FULL



LIGHT CURVE WITH GPS FLASHES – PRE EVENT



MEASURING THE OFFSETS – EXCEL CALCULATOR

- Automates and streamlines the calculation
- Visual selection aid for data processing
- Some error checking
- Calculates acquisition delays and corrected UTC for flashed frames
- Calculates interpolated acquisition delay and interpolated UTC for event frame

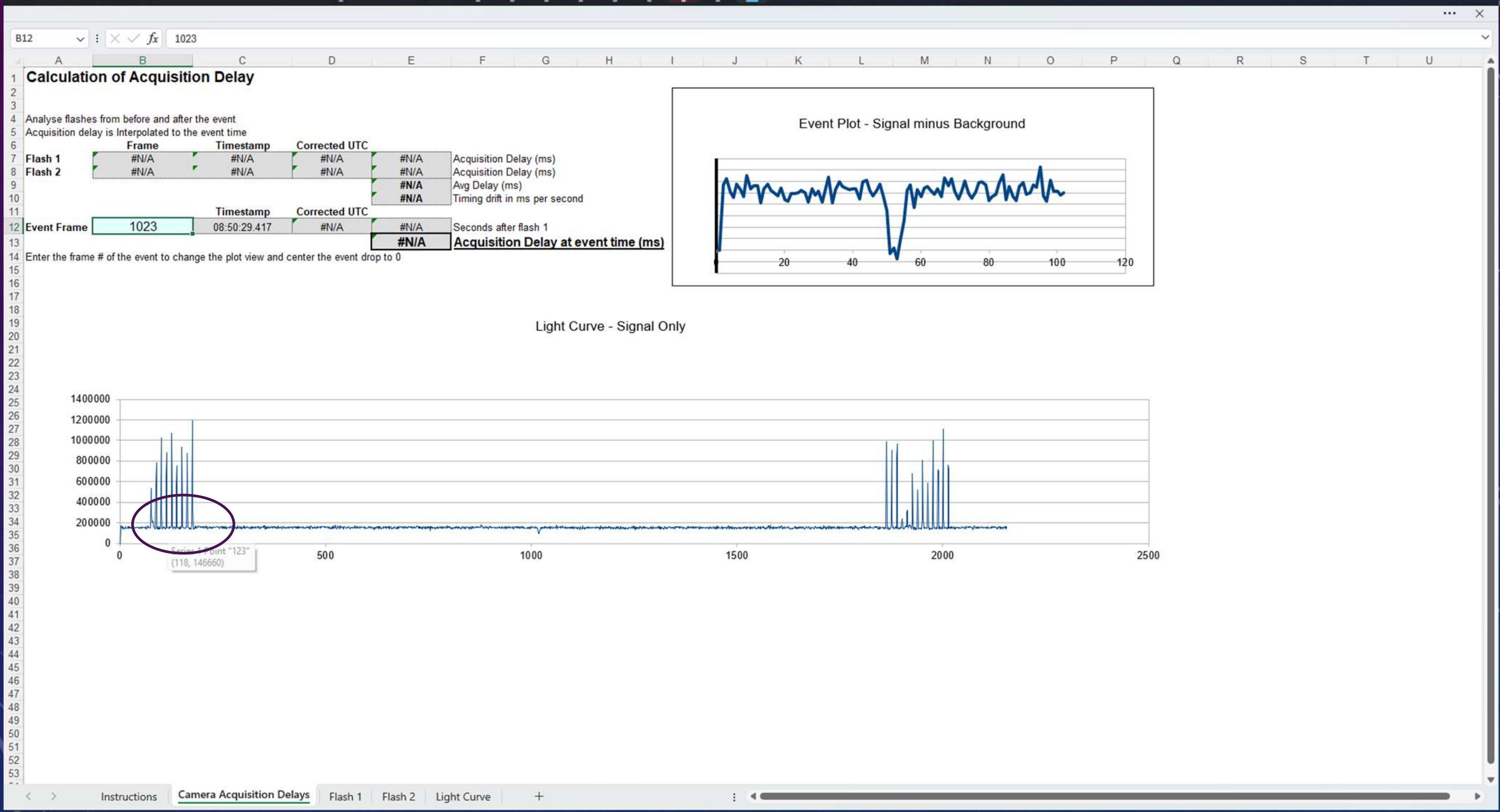
COPY THE LIGHT CURVE CSV INTO CALCULATOR

A1 | Tangra v3.7.0.5

	A	B	C	D	E	F	G	H	I	J	K
1	Tangra v3.7.0.5										
2	Measurments of 3 objects										
3	C:\Users\admin\Occultations\20240316 (17374) 1981 EF4\(17374) 1981 EF4 2024-03-16T08_49_07Z.adv										
4	Asteroidal Video (ADV2.16)	Time: Timestamp Saving During Recording									
5											
6											
7	Reversed Gamma	Colour	Measured Band	Integration	Digital Filter	Signal Method	Background Method	Instrumental Delay Corrections	Camera	AAV Integration	First Frame
8	1	no	GrayScale	no	NoFilter	AperturePhotometry	AverageBackground	Not Required	asi462mm		7
9											
10	Object	Type	Aperture	Tolerance	FWHM	Measured	StartingX	StartingY	Fixed		
11	1	OccultedStar	4.16	5.13	3.07	yes	246.3	246.7	no		
12	2	GuidingStar	4.16		2.69	yes	180.8	221.7	no		
13	3	GuidingStar	4.16		2.62	yes	118.7	64.1	no		
14											
15											
16	FrameNo	Time (UT)	Signal (1)	Background (1)	Signal (2)	Background (2)	Signal (3)	Background (3)			
17	7	[08:49:08.132]	158720	98754	169510	100120	297600	99021			
18	8	[08:49:08.212]	167840	102200	153820	104190	297430	100830			
19	9	[08:49:08.292]	159000	101950	152700	104080	310120	102160			
20	10	[08:49:08.372]	152400	103560	150610	101490	322860	98812			
21	11	[08:49:08.452]	159320	104220	167530	104150	292950	99488			
22	12	[08:49:08.532]	139570	101250	151320	101380	273630	99732			
23	13	[08:49:08.613]	158260	100220	159240	95560	266480	99513			
24	14	[08:49:08.692]	148230	100790	155590	102940	290010	98348			
25	15	[08:49:08.772]	146980	101400	159380	102180	296900	96966			
26	16	[08:49:08.852]	146800	98435	154410	102510	303080	101140			
27	17	[08:49:08.932]	141250	103010	145060	101490	287230	98519			
28	18	[08:49:09.012]	145510	99350	151050	99999	301560	100590			
29	19	[08:49:09.092]	162830	98372	158090	106590	279200	103030			
30	20	[08:49:09.172]	157400	104730	146340	102490	270010	100160			
31	21	[08:49:09.252]	147440	101390	143440	101970	301450	99851			
32	22	[08:49:09.332]	150490	103230	153550	101270	293290	100290			
33	23	[08:49:09.412]	151070	101290	158060	101530	289920	97795			
34	24	[08:49:09.492]	144200	101850	152860	100980	298680	101570			
35	25	[08:49:09.572]	160240	98434	154870	99871	314450	101960			
36	26	[08:49:09.652]	150260	104850	154760	101060	303510	99157			
37	27	[08:49:09.732]	159140	98859	154270	104270	296370	99288			
38	28	[08:49:09.812]	162010	102230	149790	101810	307630	100470			
39	29	[08:49:09.892]	150960	105450	153960	101460	287610	101760			
40	30	[08:49:09.972]	154820	101190	159300	97844	318240	106930			
41	31	[08:49:10.052]	157410	105250	163700	101820	297860	99581			
42	32	[08:49:10.132]	144460	97220	153910	104250	326690	100210			
43	33	[08:49:10.212]	154840	100900	151700	101830	290950	98517			
44	34	[08:49:10.292]	158580	105320	151390	102580	277990	99649			
45	35	[08:49:10.372]	147620	101990	158210	96420	305840	101680			
46	36	[08:49:10.452]	160450	104260	156580	99615	329860	99502			
47	37	[08:49:10.532]	155310	102040	160730	102250	315740	103570			
48	38	[08:49:10.612]	153640	102190	156950	93244	271290	100190			
49	39	[08:49:10.692]	157900	103810	155490	101610	309920	98292			
50	40	[08:49:10.772]	152120	102510	156690	100140	294080	99916			
51	41	[08:49:10.852]	149820	105300	172300	103430	311600	101050			
52	42	[08:49:10.932]	149730	103800	145070	99798	276490	100980			
53	43	[08:49:11.012]	153220	102970	150080	98498	299030	102460			
54	44	[08:49:11.092]	152790	99271	161750	99388	304530	99358			

Instructions | Camera Acquisition Delays | Flash 1 | Flash 2 | Light Curve

VIEW DATA AND IDENTIFY PRE-EVENT FRAMES



SELECT PRE-EVENT FRAMES AND MEASURE DELAY

G1 | 80

Acquisition Delay for …

Set Background

					G		
					80		
				…d	110,000		
				…nd	101,280		

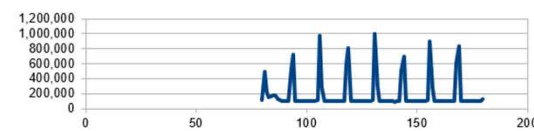
FrameNo	Time (UT)	Signal (1)	BackGround (1)	SmB (1)	Flash Event	Background Event	Signal	Background
80	[08:49:13.972]	162,070	113,120	12,881	0	0	0	0
81	[08:49:14.052]	532,220	486,500	386,261	0	0	0	0
82	[08:49:14.132]	280,280	222,860	122,621	0	0	0	0
83	[08:49:14.212]	210,890	145,390	45,151	0	0	0	0
84	[08:49:14.292]	219,380	164,900	64,661	0	0	0	0
85	[08:49:14.372]	218,180	174,340	74,101	0	0	0	0
86	[08:49:14.452]	217,490	174,910	74,671	0	0	0	0
87	[08:49:14.532]	166,790	126,790	26,551	0	0	0	0
88	[08:49:14.612]	162,150	111,630	11,391	0	0	0	0
89	[08:49:14.692]	148,950	98,396	-1,843	0	1	0	98,396
90	[08:49:14.772]	146,610	101,120	881	0	1	0	101,120
91	[08:49:14.852]	147,150	102,420	2,181	0	1	0	102,420
92	[08:49:14.932]	140,820	99,163	-1,076	0	1	0	99,163
93	[08:49:15.012]	571,880	528,060	427,821	0	0	0	0
94	[08:49:15.092]	786,550	714,450	614,211	0	0	0	0
95	[08:49:15.173]	146,000	100,650	411	0	1	0	100,650
96	[08:49:15.252]	140,630	100,250	11	0	1	0	100,250
97	[08:49:15.332]	161,230	99,373	-866	0	1	0	99,373
98	[08:49:15.412]	142,400	96,108	-4,131	0	1	0	96,108
99	[08:49:15.492]	150,280	98,749	-1,490	0	1	0	98,749
100	[08:49:15.572]	143,050	100,560	321	0	1	0	100,560
101	[08:49:15.652]	160,880	100,830	591	0	1	0	100,830
102	[08:49:15.732]	144,480	100,750	511	0	1	0	100,750
103	[08:49:1[illegible]	[illegible]	[illegible]	[illegible]	0	1	0	102,190
104	[08:49:1[illegible]	[illegible]	[illegible]	[illegible]	0	1	0	99,039
105	[08:49:1[illegible]	[illegible]	[illegible]	[illegible]	1	0	15,901	0
106	[08:49:1[illegible]	[illegible]	[illegible]	[illegible]	1	0	######	0
107	[08:49:1[illegible]	[illegible]	[illegible]	[illegible]	1	0	######	0
108	[08:49:1[illegible]	[illegible]	[illegible]	[illegible]	0	1	0	103,170
109	[08:49:1[illegible]	[illegible]	[illegible]	[illegible]	0	1	0	100,680
110	[08:49:16.372]	151,060	99,141	-1,098	0	1	0	99,141
111	[08:49:16.453]	161,200	103,660	3,421	0	1	0	103,660
112	[08:49:16.533]	153,480	100,960	721	0	1	0	100,960
113	[08:49:16.613]	154,440	101,960	1,721	0	1	0	101,960
114	[08:49:16.692]	147,610	100,480	241	0	1	0	100,480
115	[08:49:16.773]	148,210	101,360	1,121	0	1	0	101,360
116	[08:49:16.852]	139,390	101,590	1,351	0	1	0	101,590
117	[08:49:16.933]	146,430	101,050	811	0	1	0	101,050
118	[08:49:17.013]	647,910	592,990	492,751	0	0	0	0
119	[08:49:17.093]	878,340	813,520	713,281	0	0	0	0
120	[08:49:17.173]	155,120	100,200	-39	0	1	0	100,200

Tag frames to measure

Delay Calculated

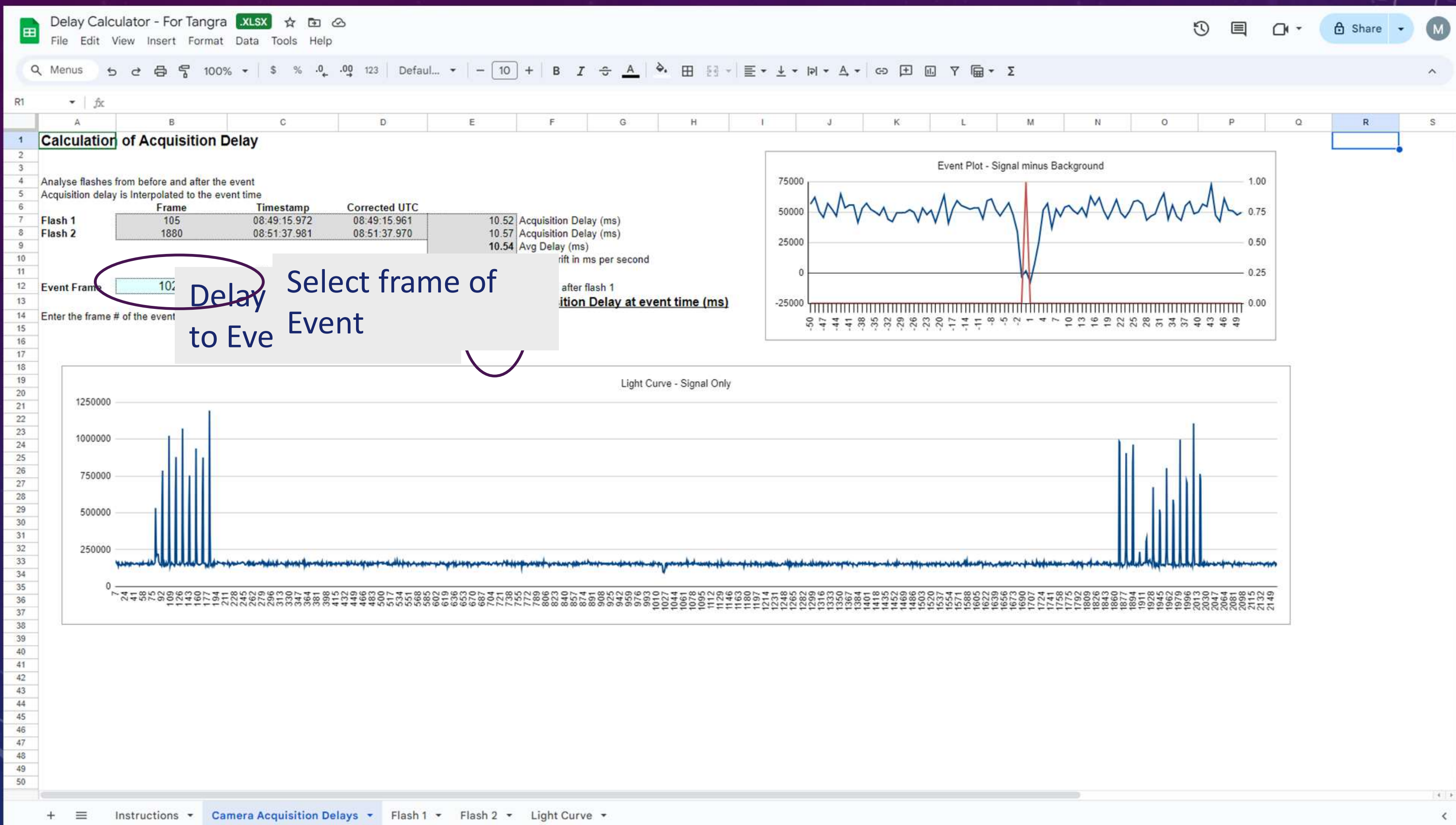
Set Exposure

Avg Acquisition Delay (ms)	**10.4**			
Exposure (ms)	**80**	Enter the		
Calculated Exposure (ms)	80			
PPS Flash Duration (ms)	100			
Flux Total	1,072,994		# Frames Flash	3
Flux 1	15,901		Flux Last	185,
Avg Background	100,239			
Unit Flux (per ms)	10,730			
PPS duration in first frame	1.5	Flux 1 / Unit Flux	PPS duration in last frame	17
Time (UT) PPS1	[08:49:15.972]		Time (UT) PPS1	[08:49:
Time (UT) PPS1 HH	8	Hours	Time (UT) PPS1 HH	8
Time (UT) PPS1 MM	49	Minutes	Time (UT) PPS1 MM	4
Time (UT) PPS1 SS	15.972	seconds and ms	Time (UT) PPS1 SS	16.
Time (UT) PPS1 (s)	31,755.972	Frame mid time in (UT) seconds	Time (UT) PPS1 (s)	31,75
T_END	31,756.012	Time (UT) PPS1 + Exposure /2	T_START	31,75
T_PPS	31756.000	Integer part T_END – (UT) of PPS	T_PPS	3175
T_END PPS	31756.001	T_PPS + PPS flash duration	T_END PPS	3175
Acquisition Delay (ms)	**10.5**	T_END – T_END PPS	**Acquisition Delay (ms)**	**10**



Instructions | Camera Acquisition Delays | Flash 1 | Flash 2 | Light Curve

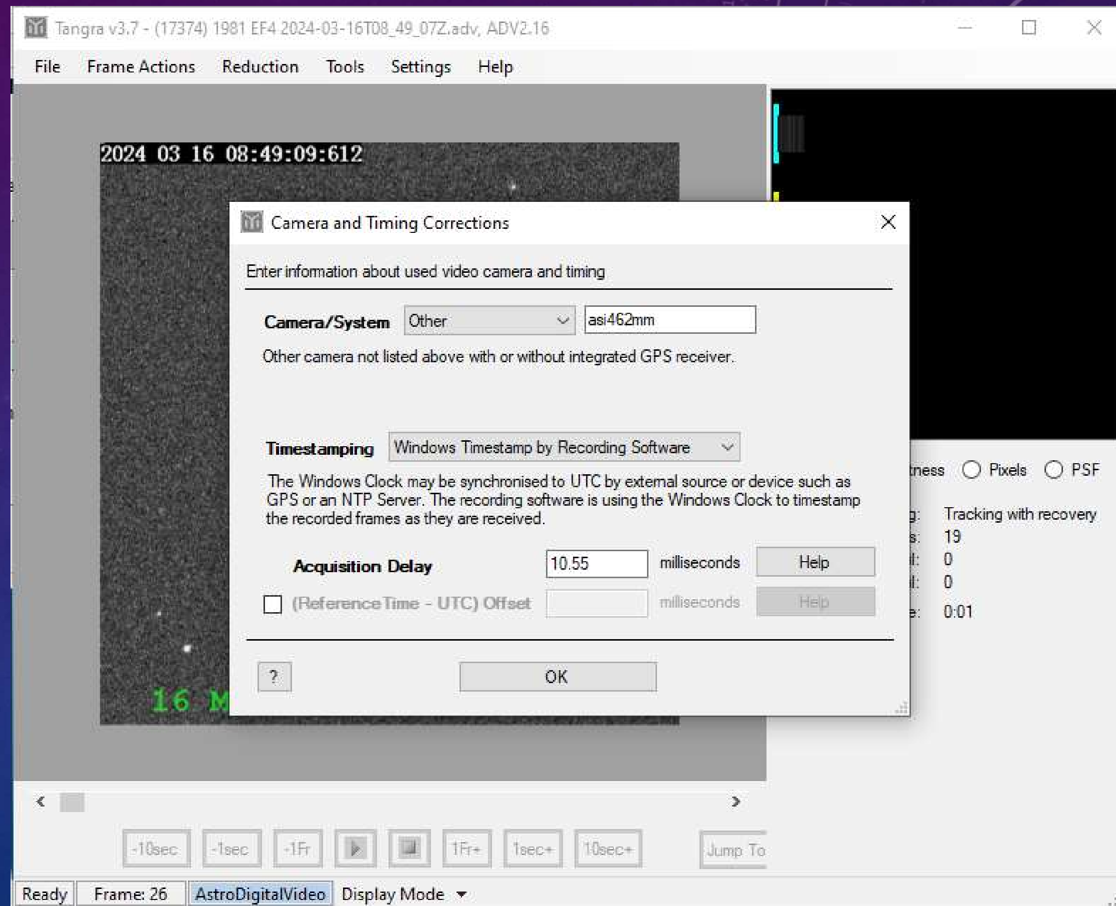
FINAL DELAY CALCULATION AT EVENT TIME



APPLYING THE DELAYS IN TANGRA

- Do a new light curve reduction in TANGRA using a subset excluding the GPS flashes
- Enter the delay when the screen pops up
- If the delay is positive enter it as an Acquisition Delay, and disable the NTP box
- If the delay is negative set the Acquisition Delay to zero, enable the NTP time reference box and enter the delay as a positive (e.g. -12 ms is entered as +12 ms)
- Light curve times are now corrected as at the event time
- Generate light curve and CSV and do AOTA analysis as normal
- Do not make any further time adjustments in AOTA

- Can also use the flash frame UTC times directly in PyOTE



TROUBLESHOOTING

How to know if something has gone wrong and what to do about it

- Check the NTP offsets as you set up
  - Windows command prompt, command "ntpq –p"
  - NTP Offset should be small, a few to low tens of ms
  - If very large offset restart the NTP service
- Log the NTP offsets
  - setup LOOPSTATS in Meinberg NTP and use the NTP monitor
- Check measured delay offsets are as expected
  - Know your typical offsets (mine are usually +10 to +20 ms)
  - Very large GPS delays (hundreds of ms) could indicate a GPS lock failure
  - If your GPS flasher stops and starts be suspicious
- If the GPS flash timing has failed can use the NTP timing as a backup time source with separately measured camera acquisition delays

Command Prompt

```
C:\Users\admin>ntpq -p
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
+time.cloudflare 10.46.8.110      3 u   32   64   37    3.533   +0.645  32.112
*159.196.3.239 ( .PPS0.           1 u   39   64   37   50.213   -4.222  34.214
+ntp3.ds.network 202.70.69.81     2 u   37   64   37  281.979  +10.937  32.215
+edge.txryan.com 233.119.138.126  2 u   36   64   37  196.099   +3.541  35.628
+50.205.57.38    .GPS.            1 u   34   64   37  209.385   -0.354  32.982

C:\Users\admin>
C:\Users\admin>ntpq -p
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
+time.cloudflare 10.46.8.110      3 u    -   64  377    3.518   -0.157   5.195
*159.196.3.239 ( .PPS0.           1 u    5   64  377   46.743   -7.050   4.506
-ntp3.ds.network 202.70.69.81     2 u    6   64  377  281.223  +11.031   4.299
-edge.txryan.com 233.119.138.126  2 u    4   64  377  189.889   +1.204  12.321
+50.205.57.38    .GPS.            1 u    2   64  377  207.448   -4.276   5.608

C:\Users\admin>ntpq -p
     remote           refid      st t when poll reach   delay   offset  jitter
==============================================================================
+time.cloudflare 10.46.8.110      3 u    1   64  377    3.495   -3.385   4.282
*159.196.3.239 ( .PPS0.           1 u    -   64  377   46.621   -5.951   3.751
-ntp3.ds.network 202.70.69.81     2 u    7   64  377  280.979   +7.353   4.902
-edge.txryan.com 233.119.138.126  2 u    5   64  377  205.069   +4.088  15.885
+50.205.57.38    .GPS.            1 u    6   64  377  207.959   -4.778   5.000
```

HOW ACCURATE IS GPS FLASH TIMING FOR REAL WORLD OBSERVATIONS?

- Real world SNR means lower accuracy than bench tests
- All will be revealed in upcoming JOA paper
- Accurate enough ***when done properly***…
- Some issues to be aware of:
  - Dropped Frames
  - Rolling shutter camera line delays – target drift in Y
  - PC time drift

DROPPED FRAMES

- Frames can drop when the exposure is too short for the camera/acquisition system
- Effect depends on how frames are allocated time stamps
- PyOTE assumes there are no dropped frames
  - Calculates average exposure time and populates timestamps
  - Each dropped frame could result in up to a 1 frame timing error
- TANGRA applies delay correction to each frame timestamp
  - Dropped frames do not affect the timestamps of valid frames

- Must check for dropped frames
- If affected attempt correction using AOTA frame editor
- *Always record with frame timestamps so can detect and fix*

GLOBAL VS ROLLING SHUTTER CAMERAS

- Global Shutter cameras are best as the entire frame exposed at the same time and delays are easy to measure
- Rolling Shutter cameras have time delays in Y axis which can cause errors in the timing
  - Time delay with each Y line up to 10-20 ms total from top to bottom – *depends on the camera*
  - Measured time will drift with target drift in Y direction – *depends on the mount*

To correct:

- Measure at the same Y line as the target star at time of event or:
- Measure the tracked star and interpolate in frame/time or:
- Measure the delay per line and apply corrections based on the Y positions at time of flash measurements and the event time

TARGET DRIFT, MOUNTS AND ROLLING SHUTTER CAMERAS

- The target star will usually drift due to tracking errors and mount mis-alignment
- Any drift in the sensor Y axis will affect the timing and will cause errors
- The error and correction required ***depends on the mount type***:
  - A **well guided mount** needs no correction for drift of a few pixels or less
  - **Pre-point mounts** will have constant Y drift which can be corrected by interpolation
  - **EQ mounts with sensor aligned with DEC** in the Y axis (up/down with orientation of 0° of 180° to N) will have linear Y which can be corrected by interpolation
  - **EQ mounts with sensor not aligned** will have non-linear drift caused by the RA motor. Cannot be fully corrected by interpolation
  - **Alt-Az mounts** have no predictable drift pattern. Cannot be fully corrected by interpolation

MEASUREMENT OPTIONS FOR ROLLING SHUTTER CAMERAS

- Where to place the measurement aperture?
- How to do the calculation or correction?

- A fixed measurement aperture at the same Y line as the target start at the time of the event
  - Requires no further correction
  - Safest and most accurate method

- A tracked aperture on the target star or the same Y line:
  - Can be corrected by interpolation to the event time/frame IF there is no Y drift or linear Y drift

- Any other placement – fixed or tracked or if Y drift is not linear
  - Can ONLY be corrected by measuring the Y line at the times of the flash measurements and applying the Y line delay corrections
  - Y line delays must be measured for the same recording – must have the same ROI, exposure, binning, 8/16 bit setting etc.
  - Can make a ‘library’ of line delays for various settings but not recommended due to extra complexity

WHICH MEASUREMENT APERTURE TO USE WITH ROLLING SHUTTER CAMERAS

Mount Type	Anywhere in Frame	Fixed at Y line at event	Tracking Target Star
Well Guided Mount	Only with Line Delay corrections	**Best**	***With or without interpolation***
Pre-Point Mount	Only with Line Delay corrections	**Best**	***OK with interpolation***
EQ with sensor Y aligned to DEC	Only with Line Delay corrections	**Best**	***OK with interpolation***
EQ with sensor Y not aligned	Only with Line Delay corrections	**Best**	Only with Line Delay corrections
Alt Az Mount	Only with Line Delay corrections	**Best**	Only with Line Delay corrections

PC TIME DRIFT

- Methods of Le Cam and JOIN/IOTA-EA use the PC time and if this drifts and lags during the observation this will affect the measured offsets and affect the corrected timestamps
- Newer PCs with more powerful processors tend to drift less than older, slower PCs
- Time drift will usually be slow and approximately linear
- Need to check and understand how stable your PC time is
- Interpolation to the event frame/time will correct for a linear drift in the PC time

GOOD PRACTICE RECOMMENDATIONS

- General Recommendation:
  - Use Pre and Post event flashes
  - Measure and track target star or fix at Y position of event
  - Interpolate to event time
- Largely or fully corrects for rolling shutter line drift and PC time drift

PC TIME DRIFT

- Methods of Le Cam and JOIN/IOTA-EA use the PC time and if this drifts and lags during the observation this will affect the measured offsets and affect the corrected timestamps
- Method of JOIN/IOTA-EA which uses an off-axis guider to illuminate the sensor frame directly is not affected by time drift as the offset at the time of the event is measured directly
- Interpolation to the event frame/time will correct for a linear drift in the PC time
- For NTP time the PC time drift should be slow and approximately linear once the NTP time has stabalised. This will be system dependent so check your own systems performance. The NTP logs will be useful
- NMEATIME2 disciplines the clock much more frequently and aggressively than NTP. The offset logs will give an idea of how that behaves. It is NOT linear drift, but if the variation in offset it small (1-2 ms) can perhaps be safely ignored
- For a one off time sync using BktTimeSync the PC time will likely drift after the sync and that drift will likely be linear. Check your system by doing test resyncs to understand your typical drift rate and how close to an observation you should sync
- Newer PCs with more powerful processors tend to drift less than older, slower PCs

WRAPPING UP

- GPS flash timing can give accurate times for occultation using simple and cheap equipment and simple processes
- Can be used to measure PC time offsets and camera acquisition delays for NTP timing
- Requires careful preparation to ensure reliable PC times, correct GPS flash timing procedures and analysis processes suitable for the particular equipment setup
- Observers need to understand the issues around Global and Rolling shutter cameras and mount types to ensure correct procedures are adopted
- Protocols for GPS flash timing should be adopted by IOTA to give sound guidance to observers to ensure that good timing accurate is achieved

REFERENCES

- HiLetgo VK172 http://hiletgo.com/ProductDetail/2156993.html
- Le Cam camera acquisition delay method
  https://nocturno.fr/acquisitiondelay/acqd_en.html
  https://nocturno.fr/acquisitiondelay/AcquisitionDelayMeasurement_EN_220915.pdf
- IOTA EA/JOIN method
  https://groups.io/g/IOTAoccultations/files/OccultationObservationMethodCMOScameraRev4.pdf
- PC timing software:
  - Meinberg NTP https://www.meinbergglobal.com/english/sw/ntp.htm
  - NMEATIME2 https://www.visualgps.net/#nmeatime2-content
  - BktTimeSync https://www.maniaradio.it/en/bkttimesync.html

- Excel Calculator and documentation will be published soon and notified on TTOA/IOTA groups